FINAL REPORT

Senior Review of

Astrophysics Mission Operations and

Data Analysis Programs

Submitted to:

Chief Scientist, Research Program Management Division

Office of Space Science

NASA Headquarters

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I. INTRODUCTION

The 1996 Senior Review of Astrophysics Mission Operations and Data Analysis Programs was convened on July 29-31, 1996. The Senior Review panel was charged with ranking the expected scientific returns of eight Astrophysics missions -- ASCA, CGRO, EUVE, ISO, ROSAT, SAX, SVLBI, and XTE -- for two periods of two years each: FY '97-'98 and FY '99-'00.

The paradigm of evaluating on the basis of "science per dollar", while difficult, is necessary in an era when funds for space science are extremely limited. It is sobering to realize that the drive for cost savings could lead to termination of observatories while they are still obtaining valuable data, or to an early reduction of operations immediately after prime phase. The scientific returns from these Astrophysics missions are reduced in order to save an amount that is typically a few percent of the cost to construct and launch the mission.

Although new missions will arrive bringing powerful new capabilities, satellites launched previously remain vigorous and long-lived and their impressive scientific accomplishments accumulate. A delicate balance must be achieved in order that the enthusiasm and high interest of both astronomers and the public for space science discoveries proceeds undiminished.

We note that a major shift has occurred in the missions considered by this Senior Review. The majority of the missions, six out of nine, represent US access to observations from the satellites of other nations. In the last Senior review only two out of eleven missions were non-US. With non-US missions, US scientists are frequently able to obtain observations which are scientifically outstanding and extremely cost-effective.

II. RECOMMENDATIONS

During its deliberations, the Committee arrived at a ranking of Astrophysics missions (see accompanying table and Section III) as well as five general policy recommendations:

1. SCOPE OF CHARGE

The Committee believes that meaningful optimization of total scientific effort occurs only when broad comparisons are possible.

The last Senior Review in 1994 requested that the 1996 Review "consider the full range of science supported by the Astrophysics MO&DA program, including the LTSA, ADP, and ATP programs." This activity was not scheduled for this Senior Review because we concentrated on programs with near-term concerns, such as mission extensions or severe underfunding. However, this Committee urges that such a charge be included in the scope of the Astrophysics Senior Review in 1998.

In addition, we urge in the strongest terms that the relevant portions of the HST and AXAF MO&DA budgets (including Science Center, Guaranteed Time Investigators, and Guest Investigator funding) be included for review and prioritization along with the other missions and programs in the next Astrophysics Senior Review Committee. It is simply not possible to recommend an optimal distribution of precious funds for science exploitation of astrophysics missions when the largest part of the budget is declared off-limits.

Finally, the MO&DA items for other missions not directly included for consideration should also be provided to the Senior Review Committee so that the competed missions can be evaluated in the context of the total program. We emphasize this scope since it is clear the the diminishing MO&DA funds may require drastic recommendations. To make the best use of restricted funds, the Astrophysics Senior Review should weigh all programs rather than be bounded arbitrarily.

Given the newly unified Office of Space Science, our Committee urges that similarly rigorous MO&DA comparisons be undertaken as soon as possible within each discipline in OSS, so that in the future, Astrophysics missions are not subjected to stricter reviews than other OSS missions.

2. MULTIPLE SOFTWARE SYSTEMS

The Committee is concerned about the proliferation of multiple software systems and the resultant incompatibilities for reduction and analysis of mission data. Some of this proliferation results from the access of US investigators to mission data from experiments of other countries; other examples occur among NASA's own satellites. Such a situation not only adds complexity, cost, and barriers to fast and efficient reduction and scientific analysis of results for the Guest Observers, but also contributes to the overall support costs of missions. Thus, less science is produced for the funds invested.

The Committee strongly urges that the activities of the former Science Operations MOWG for Astrophysics be reinstated. Their careful scrutiny and oversight of the plans and operations of the data handling and support for missions can bring pressure to bear for similar and compatible software.

3. GUEST INVESTIGATOR PROGRAMS

For missions no longer in their prime phase, or missions without significant NASA participation (e.g. ASCA, SAX, ROSAT, EUVE), this Review Committee recommends transferring the funds for Guest Investigators into the ADP budget line. Although this recommendation will require two proposals from a Guest Investigator for an ongoing mission, one for observing time and another for funds, we believe that the opportunity to combine Guest Investigator grants for analysis of data from different missions, and to access both archival and new data will result in stronger scientific programs, and allow a GI to propose for one program with continuity and scientific focus. The present schedule in which proposals for observing time are due in the summer-fall, and the ADP program deadlines occur the following January, also works well for GI's seeking funding for new satellite observations.

Addressing a related issue, the Committee believes that a program of Astrophysics Fellows, perhaps similar to the Hubble Fellows, can lead to enhanced return on our investment in space science missions. Outstanding young

scientists, competitively selected, and allowed to be independently creative, can broaden and enrich NASA's current research efforts. We encourage NASA to explore the initiation of a such a broad Fellowship program.

4. COST EFFICIENT OPERATIONS

In past years, the Committee has encouraged individual missions to conserve allotted funds in order to derive the most scientific benefit through an extended mission life. This Committee endorses that philosophy, and asks NASA to reward such savings by allowing those programs that have accumulated savings to use them for mission extensions.

5. REVIEW OF DATA CENTERS

The Committee believes it worthwhile to evaluate periodically the performance of all science services in order to optimize their science usefulness and their cost effectiveness. Specifically, the Infrared Processing and Analysis Center (IPAC) and the High Energy Astrophysics Science Archive and Research Center (HEASARC) were set up in the late 80's after recommendations from the science community. It is time now to initiate periodic comparative reviews and/or recompetitions of all discipline and mission science centers. These actions should assure that the science centers serve today's science needs, use today's technology, and fit today's financial constraints.

III. COMMENTS ON INDIVIDUAL MISSIONS

Missions are listed in alphabetical sequence.

Advanced Satellite for Cosmology and Astrophysics (ASCA)

Science Strengths

The ASCA mission is an imaging spectroscopic telescope with large collecting area, that has led to study of a broad range of astronomical objects at a relatively low cost because satellite control and mission operations is provided by the Japanese ISAS. This mission has made major contributions for a very wide range of astronomical sources. In the near future, one of the prime science goals is the study of gas orbiting supermassive black holes in active galactic nuclei (AGN), which will be accomplished by observing the shape and time variation of the Fe K-alpha line. The gas scintillation proportional counters (GSPCs), the primary instrument for hard sources, continue to operate without degradation. Another important large project will be to understand the many bright but previously unknown X-ray sources that were discovered by the ROSAT All-Sky Survey, only recently released. Important observations are continuing to be obtained for supernova remnants, X-ray binaries, cataclysmic variables, clusters of galaxies, stars, and AGNs. In addition to their scientific value, these observations will be of significant assistance in planning observations by future X-ray observatories such as AXAF and XMM.

The ASCA Guest Observer Facility has worked well with the Japanese team at ISAS to plan, obtain, and distribute a large amount of data to a substantial user community.

Science Weaknesses

For extended sources, the point spread function of the instrument complicates the extraction of spectral quantities. Shortcomings in the calibration of the detectors at low energies have hampered the analysis of spectra. The performance of the X-ray CCDs (the SISs) has decreased in terms of the number of CCDs that can be used simultaneously and their spectral resolution, although they continue to obtain valuable data.

Recommendation

ASCA continues to produce exceptional science, a situation that we expect to continue for several years. The high ranking of this program (2/8) reflects the range of scientific goals that are being addressed at moderate cost, due to the collaboration with the Japanese. The program should be maintained at a vigorous level through the launch of AXAF, and at a declining level through FY2000. We strongly encourage a continuation of efforts to cross-calibrate ASCA with other current missions (i.e., XTE, EUVE, ROSAT, and SAX) and with AXAF in 1998. Also, we recommend that important data products, such as spectra and light curves, be produced by the ASCA GOF for access through the archive. It is recommended that funds for analysis of new observations will be competed for through the ADP program, which is being augmented to accommodate this need.

Compton Gamma Ray Observatory (CGRO)

Science Strengths

CGRO covers six decades of frequency of the electromagnetic band, from about 30 keV to 30 GeV, and has brought gamma ray observations into the main stream of astronomy. Launched in 1991, CGRO has been responsible for many significant discoveries. Notable are the isotropy of the gamma ray bursts (GRB), the discovery of gamma ray quasars, gamma ray pulsars, direct detection of recently formed elements (nucleosynthesis), and mapping of the diffuse emission from our Galaxy, from the Universe in the 511-keV annihilation line and the 26Al lines. Long term studies of accretion powered pulsars and the discovery and follow-up of X-ray transients have also been very productive enterprises.

The proposed future programs include the continued operation of all the instruments except EGRET which has a lifetime of 1 year, limited by a consumable (spark-chamber gas). BATSE detects, on average, about one burst a day. Over the next five years, the BATSE catalog can be doubled to 3000 bursts and this may lead to new constraints on repetition (or lack of it) and the burst distribution on large scales. By means of BACODINE, crude positions of gamma ray bursts are made available on the Internet for prompt follow up at radio and optical wavelengths.

Continued imaging of the Galactic plane in the 26Al line by COMPTEL will improve the significance of the detections. Imaging in the 44Ti line may show us sites of the youngest supernovae. New transients keep appearing on the sky and CGRO is well suited to their detection and detailed study. Finally, we note that GRO will be the only gamma-ray mission that will be operational during the next solar maximum which starts in 1999, although the Committee did not feel it had the competence to judge the scientific significance of this capability.

Science Weaknesses

Gamma ray sources are quite faint. Thus significant improvements in detection sensitivities would require very long integration times and a mission duration comparable to the prime time phase duration of five years. While BATSE will be useful for the detection of new transients there are other recent missions that have significant overlap in the area of transient detection and accretion powered pulsars. BATSE is quite limited in its ability to localize Gamma-Ray Bursts, and it is unclear that the mystery of Gamma-Ray Bursts will be resolved simply by increasing the size of the present sample.

Recommendation

CGRO has achieved, indeed exceeded, its stated goals, but it now is entering an era of diminishing science returns. It is desirable to maintain the BATSE capability until there is another mission available to address the nature of Gamma-Ray Bursts. Within this priority, the four instruments aboard GRO should continue to operate as long as possible. The Committee recommends that beginning in FY97, Instrument PI teams compete with Guest Investigators for all science grants support.

The solar community needs to be consulted about the importance of observations with CGRO during solar maximum.

It is crucial that efforts concentrate on techniques such as BACODINE that hold the promise of individual source identifications. The Committee encourages the GRO Project to maximize the effectiveness of the ground-based component of the BACODINE network.

The PI instrument teams should make a more vigorous effort to archive their data in a useful way in the HEASARC. The instrument teams should work with the HEASARC to produce software tools needed to access the archival GRO data.

Extreme Ultraviolet Explorer (EUVE)

Science Strengths

EUVE fills a unique spectral region that is replete with a rich spectrum of atomic and ionic lines representing a wide sampling of energies from 10^4 to over 10^7K. Both spectroscopy and photometry are possible covering the region 70 to 700A. During its prime mission, followed by its extended mission phase, the scientific returns from EUVE have been impressive. Significant contributions to many areas of astrophysics have resulted, among them cool star coronas, hot star photospheres, white dwarf atmospheres, cataclysmic variables, and the structure of the interstellar medium. Spectroscopy in the EUV region provides a complement to low resolution observations of ASCA for point sources. EUVE has developed innovative and cost-savings approaches to satellite operations, and has dealt well with software, data distribution, and educational outreach.

Science Weaknesses

Balanced against these strong points, the Committee finds that the scientific case for extending the EUVE mission a second time is not as compelling in comparison to plans for other missions in the competition. Many of the brightest targets accessible to EUVE have been measured; remaining targets will require long integration times. Some of the programs proposed for this EUVE extended mission could be carried out more effectively in other ways.

Recommendation

For the final years of EUVE, the Committee encourages observations that focus on the unique strengths of the mission, such as the study of nearby objects. The Committee recommends that EUVE mission operations continue through FY'97. Funds for the EUVE Guest Observer program will be distributed via the ADP program in order to allow analysis of EUVE data alone or in conjunction with other observations. Given the present budget constraints, only reduced funding for EUVE operations is available through FY97 unless additional funds are found. Within available funds, EUVE should be encouraged to explore ways to extend science observations as long as possible.

Infrared Space Observatory (ISO)

Science Strengths

The ESA Infrared Space Observatory, launched in November 1995, is the major infrared space mission of this decade. It has a complex suite of instruments for imaging, photometry, and spectroscopy at various resolutions between 2.5 and 240 micron. Already, it has achieved an extraordinary variety of observations affecting nearly all areas of astronomy. These observations are providing insight into solar system objects, cool or obscured stars, protostellar and protoplanetary regions, dusty and primeval galaxies, active galaxies, and the chemistry of the interstellar medium in the Milky Way and other galaxies. Not only will outstanding science be done, but this science will point the way to areas of infrared astronomy which will be the most exciting frontiers for SIRTF and will produce a knowledgeable community of US infrared astronomers to optimize the planning and use of SIRTF.

US astronomers participate in this billion dollar mission with guaranteed time as members of ISO instrument teams and as members of US Key projects. In addition, a large number of US astronomers (135 PIs from 56 institutions) successfully competed for ISO guest observer time, receiving 34% of the available open time. The return to the US community will be further enhanced by the significantly longer lifetime now anticipated for ISO (24 months vs 16 months), which means there will be a second opportunity for proposals. In addition, the support of proposals and data analysis provided in the US through IPAC enhances the overall efficiency of US involvement, and allows the potential for longer term data analysis and archiving tools that will benefit the entire ISO user community. In the judgment of our Senior Review, ISO is proving an outstanding success, and we are extremely pleased at the extent of involvement by US astronomers.

Science Weaknesses

The ISO instruments are complex, sensitivity is lower than expected for some instruments, and calibration is more difficult than expected because of on-orbit changes in the detectors. Nevertheless, the interface provided by IPAC between US users and the European instrumentation teams and the data analysis tools being developed at IPAC will eventually lead to adequate results for US observers.

Recommendation

This 1996 Senior Review ranks ISO number one among the missions considered in terms of scientific productivity relative to the NASA investment. In our view, the scientific return can be greatly leveraged with further modest investments. For this reason, we recommend an augmentation of both the data analysis funds for US Guest Observers as well as for the science operations, data analysis, and archiving tools at IPAC.

The needs at IPAC are more urgent since these tools need to be developed in advance of the actual observations. For the observers, the enhanced funding can await the time after observations are actually obtained. Because of the unexpectedly large number of US users, current staffing at IPAC cannot meet demand. Also, because of incomplete European plans for a data archive, IPAC must begin developing an archive.

Consequently, we recommend that the FY 97 and FY 98 ISO-related funding for IPAC be at a level of 3.6M (1M above the currently approved NASA plan for FY 97 and 0.8M above for FY 98), with the extra funding to be used only for archive development and support of US GTOs and GOs. Augmentation is recommended for data analysis funding to GOs in FY 98 (1.8M increase to 3.5M) and FY 99 (0.8M increase to 2.8M).

It appears that the cost per FTE is significantly higher at IPAC than at other data centers we examined. We strongly urge IPAC to explore methods to reduce their cost per FTE.

Röntgensatellit (ROSAT)

Science Strengths

The ROSAT mission has been extraordinarily effective in addressing many issues in X-ray astronomy, at extremely low cost to NASA. ROSAT's unique capabilities - spatial resolution of ~5 arcsec over a 40 arcmin field of view - justify continuing US participation in observations. The large amounts of HRI observing time available enable acquisition of extremely valuable high-resolution maps of large supernova remnants, crowded star clusters, the

Magellanic clouds and other nearby galaxies, and clusters of galaxies. Having a large library of such pathfinder images in the ROSAT data base will greatly increase the efficiency of AXAF.

The extensive set of unique PSPC observations is an irreplaceable trove of data on tens of thousands of faint point sources, plus many complex extended emitting and absorbing objects. It will be the basis for many studies of stellar and extragalactic astronomy, diffuse x-ray emission, supernova remnants, and galactic structure. The ROSAT Bright Source Catalog, which was recently released, includes a number of sources that can be imaged with the HRI. The recent observation of X-rays from Comet Hyakutake demonstrates ROSAT's continuing capability for making surprising discoveries.

Science Weaknesses

With the loss of the PSPC, ROSAT has virtually no spectroscopic capability. ROSAT's sensitivity is limited to soft x-rays.

Recommendation

ROSAT continues to provide an excellent opportunity to derive important and long-lasting science at an unusually low cost to NASA. The Panel recommends funding for the US ROSAT effort at approximately $1M/year for 1997-99. In addition, we recommend that some support be given to Guest Investigators on ROSAT by allowing them to propose through the ADP program. ROSAT should continue operation through the launch of AXAF, and the data archive should be completed by the end of FY 99.

SAX - (Satellite per Astronomia X "Beppo"))

Science Strengths

The unique capability of the Italian-Dutch BeppoSAX satellite is its ability to measure simultaneously, with cross-calibrated instruments, the spectrum of both galactic and extragalactic objects from 0.1 to over 100 keV. The principal science goals include measurement of the broadband spectrum of AGN, broad-band spectral monitoring of galactic X-ray binaries, and detection of X-ray (2-30 keV) counterparts to gamma-ray bursts using the Wide Field Camera.

Science Weaknesses

The effective area of the low and medium energy instruments is smaller than for other current and near-future missions; e.g., the proposed studies of external galaxies, supernova remnants, faint point sources, galaxies clusters, and stars are likely to be made with ROSAT, ASCA, AXAF, XMM, and ASTRO-E. Timing observations of bright sources can be better achieved with XTE. The approved US programs are, in general, good uses of SAX's capabilities, but do not appear to offer breakthrough opportunities.

Recommendation

It is clear that the software situation needs improvement, although there seems to be a path to providing both analysis software for US users and basic datasets for a usable archive at relatively modest costs. Given the excellent record of the HEASARC in providing cost-effective analysis tools and user-friendly archives, the Committee feels that MO&DA funding for SAX should be focused there. The Committee believes that the establishment of a SAX archive will give US scientists access to a valuable observational capability and an important archive of high energy astrophysics data at extremely modest cost. US SAX investigators should have an opportunity to propose to the ADP program for support to carry out their SAX Guest Investigator programs.

Space Very Long Baseline Interferometry (SVLBI)

Science Strengths

The Japanese VSOP mission provides a space radio telescope that together with an international array of ground-based telescopes, comprises the first Space Very Long Baseline Interferometry (SVLBI) facility. The basic scientific strength of the mission lies in the gain of a factor of three in angular resolution at the three operating frequencies compared with ground-based arrays. This improvement in angular resolution makes possible a number of important and interesting investigations. Examples include: a test of the predicted limit to source brightness temperature imposed by inverse Compton cooling, study of superluminal motions closer to the central engines of active galactic nuclei (AGN), study of accretion disk structures on subparsec scales via H2O maser emission, and imaging of galactic maser spot shapes.

Science Weaknesses

Ground-based observations at the same spatial resolution provided by SVLBI, although at higher frequencies and of admittedly poorer quality, have not yielded significant new information on AGN's. The small size (8m) of the space element means the amount of interesting science will be limited by the availability of the largest ground-based telescopes and may be restricted to the brighter 100 sources of the roughly 1000 that can be imaged by SVLBI.

Recommendation

The proposal requests data analysis support for only those PI's ineligible for NSF support - (14) individuals at JPL, IPAC, and SAO. Data analysis is complex for SVLBI and will require, at least initially, travel to NRAO-Socorro for training. Science support is important for SVLBI scientists at Federally Funded Research and Development Centers (FFRDC) who have been awarded observing time, and should be provided during the prime phase of the VSOP mission.

Overall ranking of SVLBI in this Senior Review and the constraints of the budget argue for funding at roughly one-third of the level requested.

Rossi X-Ray Timing Explorer (RXTE)

Science Strengths

The Rossi-XTE is in the first year of its prime science mission, and the first 6 months of operation have produced new and exciting results on the millisecond variability of neutron stars, bursting pulsars and the long-term variability and spectra of AGN and X-ray transients. The prime advantages of XTE over other X-ray missions are its capability for observations on extremely short timescales, its broad bandpass, and its flexible scheduling, which allows rapid observation of transient phenomena as well as long term monitoring studies of variable X-ray sources. The All Sky Monitor provides the capability for notification of new X-ray transients and the production of long term light curves for bright sources. The panel was pleased with the rapid availability of 100% open time for the entire community. The wide range of target capabilities has led to a large proposal response from the scientific community.

Science Weaknesses

The satellite and detectors were designed for observation of the brightest compact sources, so targets at low flux levels (many ROSAT sources, galaxies, SNR) are not suitable. The high and variable background is a limiting problem for many programs. No argument is made for how many sources need to be observed to achieve the scientific objectives (e.g. how many AGNs need to be observed, and for how long, in order to significantly advance the field.) It is too early to tell if the detection of Millisecond Quasi-Periodic Oscillators (MS QPOs) will solve fundamental problems with neutron stars or are merely manifestations of neutron star "weather".

Recommendation

Since this mission is still operating in its prime phase, and is accomplishing its expected science goals, the mission should be funded at adequate levels to ensure operations and data analysis during its prime mission years. After year 2, the user support should be reduced as expertise is transferred to the Guest Observers. At the next Senior Review, a reassessment of the accomplishments in terms of remaining prime science should be done. In light of the limited range of problems to be addressed by XTE and extreme demands on available funding, FTE support must be reduced in future years.

TABLE 1

Astrophysics Senior Review 1996

Numerical Rank Order of Eight Astrophysics MO&DA Programs : Average of Panel Member rankings on a scale of 1 (1 = best) to 8

Program	**97-98**	**99-00**
ISO	1.0	2.3
ASCA	2.8	2.5
ROSAT	3.8	4.3
XTE	4.0	4.5
GRO	4.8	4.6
SVLBI	6.0	5.3
SAX	6.5	5.1
EUVE	7.1	7.3